Remarks

I. Claim status.

Claims 1-13 and 23-25 are pending. With this response, claims 1-13 and 23-25 are canceled and claims 26-40 are newly added. No new matter has been added.

Newly added claims are supported by the originally filed claims. In addition, claim 26 finds support, for example, on page 7, lines 8-9, and on page 12, lines 6-8; claims 27, 36, 38 and 40 find support, for example, at page 6, lines 11-15; and claim 36 finds further support, for example, on page 9, Table 1. Reconsideration of the claims, in view of the remarks that follow, is respectfully requested.

The specification has been amended to correct a typographical error in Table 2. The chemical names in the second column have been corrected to correspond to the chemical structure indicated by the definitions of E^1, E^2, R^1 and R^4. The correct chemical name is obvious in view of the designation of E^1, E^2, R^1 and R^4. Furthermore, the correct chemical names appear in Table 2 set forth in USSN 60/131527, to which this application claims priority. A copy of Table 2 from the priority application is enclosed as Exhibit 1 for ease of reference.

II. Rejection of the claims under 35 U.S.C. § 112, first paragraph.

Claim 13 stands rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the enablement requirement as failing to show that claimed compounds are liquids at all temperatures less than 70°C.

Claim 6 stands rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement as claim 6 does not require the alkali metal and amide ligand to be in the form of a compound.

Newly added claims 26-40 do not include the objectionable claim language. The rejection may be withdrawn.

III. Rejection under 35 U.S.C. § 112, second paragraph.

Claims 2-5, 7-11 and 23-25 stand rejected under 35 U.S.C. § 112, second paragraph, as being indefinite for failure to particularly point out and distinctly claim the subject matter applicant regards as the invention. The subscript "n" is considered unclear as to the nature of the chemical structure. Furthermore, claim 7 is considered indefinite for failing to define "M".

Newly added claims 27, 36, 38 and 40 recite that "n is in the range of 1 to 3." It is submitted that the nature of association of multiple metal centers, particularly alkali metals, is well understood in the art. See, for example, Exhibit 2 (Lappert et al. "Structure and Reactivity of Sterically Hindered Lithium Amides and Their Diethyl Etherates: Crystal and Molecular Structures of $[Li\{N(SiMe_3)_2\}(Oet_2)]_2$ and $[Li(NCMe_2CH_2CH_2CH_2Cme_2)]_4$" J. Am. Chem. Soc., 1983, 105, 302-304), which describes dimers and tetramers of lithium amides. See also Exhibit 3 (J.H. Gilchrist and D.B. Collum, "Distinction of Symmetric Lithium Dialkylamide Dimers from Higher Oligomers by Inverse-Detected ^{15}N Homonuclear Zero-Quantum NMR Spectroscopy, J. Am. Chem. Soc., 1992, 114, 794-795), which describes dimer, trimers and higher oligomers of lithium alkylamides. Furthermore, the specification describes the bonding for "n" greater than 1, at page 6, lines 11-15:

The number n represents the degree of association of the molecules. Typical values of n were found to lie between two and three, corresponding to dimers and trimers. It is believed that these oligomers are attached together by bonds in which nitrogen atoms form bridges between metal atoms.

Applicants submit that the term "n" as it is used in the specification and claims of the instant application is clear and definite. The rejection may be withdrawn.

IV. Objection to the claims.

Claim 1 is objected to as failing to further limit the subject matter of a previous claim. Amended claim 1 now recites that the "vapor of said compound is at a temperature of between about 150°C and 250°C." No such limitation is found in the newly added claims. The objection may now be withdrawn.

V. Anticipation of the claims over Niecke.

Claims 11-6, 8, 12-13 and 23-25 stand rejected as anticipated by Nieke et al. in *Chimia* (1986), 40(6), pages 202-205 ("Nieke"). Nieke identifies various lithium amide compounds for use as reagents in the formation of iminophosphanes. Specifically, Nieke discloses the compound $LiN(SiMe_2tBu)_2$ (Nieke Article at page 203.[1] Nieke also discloses $LiN(SiMe_3)R'$, where R' is $SiMe_3$, $SiMe_2tBu$, CH_2tBu, 1-adamantyl, $2,4,6-tBu_3C_6H_2$ and $2,4,6-Me_3C_6H_2$. See Scheme I of Nieke at page 203.

There is no teaching or suggestion in Nieke of a lithium amide compound that is a liquid at a temperature in the range of 20-70°C and forms a vapor at a temperature of between about 150°C and 250°C, as recited in claim 26 and those dependent thereon.

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[1] The undersigned attorney thanks the examiner for indicating where in the Nieke reference the compound is identified.

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Nieke discloses the use of lithium alkyl amides as bases in the formation of iminophosphane compounds. These reactions are carried out in solution at reduced temperatures. See Experimental Section of Nieke, at pages 204-205. There is no disclosure of a lithium alkyl amide *liquid or vapor*, as recited in claim 26. There is simply no evidence, explicit or inherent, that these compound are even capable of vaporization. Even if a compound was a liquid, it does not necessarily have a vapor pressure that provides a vapor at a temperature between 150°C and 250°C. Nor would there be any suggestion or reason to form a vapor of the compound, since Nieke discloses its use in solution at temperatures below 0°C. Thus, Nieke does not anticipate or suggest the invention set forth in claims 26-35.

Nieke also does not teach the *liquid* alkali metal amide as recited in claim 36, in which "the number of angular variables of the amide in excess of those present in the reference bis(trimethylsilyl)amine is greater than six." In particular, $LiN(SiMe_2tBu)_2$ has an angular variable of 2, and $LiN(SiMe_3)R'$, where R' is $SiMe_3$, $SiMe_2tBu$, and CH_2tBu, have angular variables of 0, 1, and 1, respectively. A higher number of angular variables is associated with a greater ability to form liquid alkali metal amides at room temperature. See, Specification at page 10, lines 4-8. Nieke does not suggest the desirability of liquid alkali metal amides and thus does not suggest an alkali metal amide with a number of angular variables greater than 6.

Lastly, Nieke does not disclose any of the alkali metal amide compounds explicitly disclosed in claims 38, 39 and 40. Note that the proviso of claim 38 specifically excludes those compounds disclosed in Nieke. Furthermore, Nieke does not suggest the desirability of liquid alkali metal amides, and thus does not suggest an alkali metal amide having the recited structures that are selected to provide liquids at temperatures in the range of 20-70°C.

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For the foregoing reasons, Nieke does not anticipate (or render non-obvious) any of

claims 26-40.

VI. Anticipation of the claims over Kopka.

Claims 1-8, 13 and 23-25 stand rejected as anticipated by Kopka et al. in Chemical

Abstract Ascension Number 1986:571530 HCAPLUS ("Kopka Abstract"). The Abstract refers

to an article by Kopka et al. *Synthetic Comm.* (1986), 16(1), pages 27-34 ("Kopka"). A copy of

the Kopka article is included with this response as Exhibit 4.

In a telephone conversation on June 1, 2005, Examiner Anthony explained that the

relevant portions of the Kopka Abstract had not been sent with the Office Action and that the

teaching of the Kopka Abstract was not properly identified in the Office Action. The missing

portions of the Kopka Abstract were supplied to the undersigned on June 1, 2005, with the

understanding that the reference is relevant for disclosing the lithium amide, $LiN(CMe_2Et)_2$.

Kopka identifies various lithium amide compounds for use as reagents in the

dehydrohalogenation of 2-halobutanes. Specifically, Kopka discloses $LiNR_2$, where R is Et, *i*-Pr,

2,2,6,6-tetramethylpiperidine, $EtMe_2C$ and Et_3C. See Table I of Kopka at page 30.

There is no teaching or suggestion in Kopka of a lithium amide compound that is a liquid

at a temperature in the range of 20-70°C and forms a vapor at a temperature of between about

150°C and 250°C, as recited in claim 26 and those dependent thereon.

Kopka discloses the use of lithium alkyl amides as bases in the dehydrohalogenation of 2-

halobutanes. These reactions are carried out in solution at reduced temperatures. See Table I of

Kopka, at page 30. There is no disclosure of a lithium alkyl amide *liquid or vapor*, as recited in

claim 26. There is simply no evidence, explicit or inherent, that these compound are even capable of vaporization. Even if the disclosed compounds were a liquid, they do not inherently or necessarily form a vapor at a temperature between about 150°C and 250°C. For example, the compounds could decompose before reaching the recited temperature range. Nor would there be any suggestion or reason to provide a vapor of the compound, since Kopka discloses its use in solution at temperatures at 0°C. Thus, Kopka does not anticipate or suggest the invention set forth in claims 26-35.

Kopka also does not teach the *liquid* alkali metal amide as recited in claim 36, in which "the number of angular variables of the amide in excess of those present in the reference bis(trimethylsilyl)amine is greater than six." In particular, $LiNR_2$, where R is Et, i-Pr, $EtMe_2C$ and Et_3C, have angular variables of 0, 0, 2 and 6, respectively. A higher number of angular variables is associated with a greater ability to form liquid alkali metal amides at room temperature. See, Specification at page 10, lines 4-8. Kopka does not suggest the desirability of liquid alkali metal amides and thus does not suggest an alkali metal amide having a number of angular variables greater than 6.

Lastly, Kopka does not disclose any of the *liquid* alkali metal amide compounds disclosed in claims 38, 39 and 40. Note that the proviso of claim 38 specifically excludes those compounds disclosed in Kopka. Furthermore, Kopka does not suggest the desirability of liquid alkali metal amides and thus does not suggest an alkali metal amide having the recited structures that are selected to provide liquids at temperatures in the range of 20-70°C.

For the foregoing reasons, Kopka does not anticipate (or render non-obvious) any of claims 26-40.

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VII. Anticipation of the claims over Kosley.

Claims 1-5, 8, 12-13 and 23-25 stand rejected as anticipated by Kosley et al. in US.

Patent No. 5,145,855 ("Kosley"). Kosley is relied upon to teach the lithium, potassium and

sodium salts of bis(triethylsilyl)amide, $MN(SiEt_3)_2$.

As was the case for Nieke and Kopka, there is no teaching or suggestion in Kosley of a

lithium amide compound that is a liquid at a temperature in the range of 20-70°C and that forms

a vapor at a temperature in the range of 150°C and 250°C, as recited in claim 26 and those

dependent thereon.

Kosley discloses the use of alkali metal bis(loweralkylsilyl) amides as bases in the

formation of alkali metal alkoxides. These reactions are carried out in solution. Col. 8, l. 39-43.

There is no disclosure of a lithium alkyl amide *liquid or vapor*, as recited in claim 26. There is

simply no evidence, explicit or inherent, that these compound are even capable of vaporization.

Even if the disclosed compounds were a liquid, they do not inherently or necessarily form a

vapor at a temperature between about 150°C and 250°C. For example, the compounds could

decompose before reaching the recited temperature range. Thus, Kopka does not anticipate or

suggest the invention set forth in claims 26-35.

Kosley also does not teach the *liquid* alkali metal amide as recited in claim 36, in which

"the number of angular variables of the amide in excess of those present in the reference

bis(trimethylsilyl)amine is greater than six." In particular, $LiN(SiEt_3)$ has an angular variable of

6. A higher number of angular variables is associated with a greater ability to form liquid alkali

metal amides at room temperature. See, Specification at page 10, lines 4-8. Thus, Kosley does

not suggest the desirability of liquid alkali metal amides and thus does not suggest an alkali

metal amide having a number of angular variables greater than 6.

Lastly, Kosley does not disclose any of the *liquid* alkali metal amide compounds

disclosed in claims 38, 39 and 40. Note that the proviso of claim 40 specifically excludes those

compounds disclosed in Kosley. Furthermore, Kosley does not suggest the desirability of a

liquid alkali metal amides and thus does not suggest an alkali metal amide having the recited

structures that are selected to provide liquids at temperatures in the range of 20-70°C.

For the foregoing reasons, Kosley does not anticipate (or render non-obvious) any of

claims 26-40.

IV. Obviousness rejection.

Claims 7 and 9-11 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over

Nieke. Claims 9-11 stand under 35 U.S.C. § 103(a) as being unpatentable over Kopka or

Kosley. While acknowledging that there is no disclosure in the prior art of the features recited in

claims 7, 9, 10 and 11 (the elements are found in claims 39, 32, 33 and 34, respectively), the

Office Action asserts that these features would nonetheless have been obvious variations of the

compounds disclosed in the cited references. See Paragraphs 12-13 of Office Action dated

December 10, 2004 at pages 6-7. Applicants respectfully disagree.

The Nieke, Kopka and Kosley references disclose specific alkali metal amides as bases

for specific organic reactions. The suggestion to modify the prior art disclosure must be found

within the prior art, and not within the claimed invention. There is no suggestion in any of the

cited references to provide alkali metal amides, as recited in claim 26, or to prepare alkali metal

amides having torsional variables greater than 6 as recited in claim 36. The features of the

claimed invention relate to volatile liquid alkali metal amides. Nothing in the cited art teaches or suggests such compounds.

Most certainly, there is no teaching or suggestion of the specific compounds recited in claims 38, 39 and 40. These compounds have been made, tested and demonstrated to be liquids at 20°C. As noted in the instant specification, such volatile compounds are useful as precursors in the vapor deposition of films that contain an alkali metal. There is no guidance or suggestion in any of the prior art references directed to modify the basic alkali metal amides disclosed therein so as to obtain an alkali metal amide that is a liquid at room temperature, much less to prepare the specific compounds recited in claims 38, 39 and 40.

For the foregoing reasons, the Nieke, Kopka and Kosley do not render any of claims 26-40 obvious.

Deposit Account Authorization

Applicants hereby request that the period for responding to the outstanding Office Action be extended for three months' time. The Commissioner is hereby authorized to charge the required fee of $510.00 for filing the request for extension of time to our Deposit Account No. 08-0219.

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No other fees are believed to be due with this response. However, please charge any

additional fees or credit any overpayments to Deposit Account No. <u>08-0219</u>.

Respectfully submitted,

Date: _____

Mary Rose Scozzafava, Ph.D.
Reg. No. 36,268

Wilmer Cutler Pickering Hale and Dorr LLP
60 State Street
Boston, MA 02109
Tel: (617) 526-6015
Fax: (617) 526-5000

Exhibit 1

Other bis(trialkylsilyl)amines were made in a similar manner, by substituting other trialkylchlorosilanes for n-propyldimethylchlorosilane.

Example 2. Lithium bis(n-propyldimethylsilyl)amide was prepared by the slow addition via syringe of a hexane solution of butyl lithium (11.7 mL of 2.73 M solution, 31.9 mmol) to a stirred hexane solution (75 mL) of bis(n-propyldimethylsilyl)amine (6.93 g, 31.9 mmol) at room temperature. Stirring was continued for several hours and the solution was then refluxed for one hour. The hexane was evaporated under vacuum, leaving 5.8 g of a pale yellow liquid. It was distilled at a temperature of 130 °C and a pressure of 0.15 torr to yield 5.25 g (74%) of clear liquid lithium bis(n-propyldimethylsilyl)amide. Its viscosity was measured to be 23.3 centipoise at 40 °C.

Examples 3-12. Similar methods were used to prepare other distillable liquid lithium compounds having the properties listed in Table 2.

Table 2. Liquid lithium amides

No.	Lithium salt	E^1	E^2	R^1	R^4	Viscosity (centipoise @ 40°C)	Vapor Pressure (°C/Torr)
2	bis(n-propyldimethylsilyl)amide	Si	Si	n-Pr	n-Pr	23.3	130/0.15
3	bis(n-butyldimethylsilyl)amide	Si	Si	n-Bu	n-Bu	22.4	145/0.085
4	bis(i-butyldimethylsilyl)amide	Si	Si	i-Bu	i-Bu	32.9	145/0.05
5	bis(3,3-dimethylbutyldimethylsilyl)amide	Si	Si	Z^1	Z^1	247	225/0.9
6	bis(n-hexyldimethylsilyl)amide	Si	Si	n-Hex	n-Hex	26	
7	bis(n-octyldimethylsilyl)amide	Si	Si	n-Oct	n-Oct	45	
8	tert-amyl(triethylsilyl)amide	C	Si	Et	Z^2	162	157/0.095
9	tert-amyl(n-butyldimethylsilyl)amide	C	Si	Et	n-Bu	368	158/0.2
10	tert-amyl(i-butyldimethylsilyl)amide	C	Si	Et	i-Bu	497	145/0.1
11	tert-amyl(n-propyldimethylsilyl)amide	C	Si	Et	n-Pr	810	171/0.3
12	tert-amyl(i-propyldimethylsilyl)amide	C	Si	Et	i-Pr	409	137/0.2

$Z^1 = (CH_2)_2C(CH_3)_3$; $Z^2 = R^4, R^5, R^6 = Et$

Exhibit 2

different from those of the native protein.

The reaction of $a_3RuH_2O^{2+}$ with sperm whale myoglobin was allowed to proceed for 24 h under anaerobic conditions at pH 7, and the Ru-labeled protein was then oxidized and purified by standard procedures, to give Ru_3Mb.[11] Absences of the imidazole C-2 proton resonances of His-12, His-81, and His-113 in the high-field NMR spectrum of Ru_3Mb pinpoint those residues as the sites of attachment of the a_3Ru^{3+} groups (Figure 1).[12,13]

The three attached a_3Ru^{3+} groups do not appear strongly to perturb the Mb conformation, as judged by comparative measurements of electronic and vibrational spectra. The ability of the heme in Ru_3Mb to bind anions, however, is enhanced greatly over that of the native protein. Cyanide, for example, binds strongly both to the Fe^{III} and Fe^{II} forms of Ru_3Mb.[14] The electrostatic influence of the three a_3Ru^{3+} groups is likely responsible for this impressive change in anion affinity, as it is for the very high pI value (~9.2) for Ru_3Mb.

The reduction of O_2 by a variety of organic substrates is catalyzed quite effectively by Ru_3Mb. Good substrates for this " synthetic oxidation–reduction enzyme" include ascorbate and durohydroquinone. Comparisons of reactivity parameters (K_m, k_m) for several substrates with a_3RuIm^{3+}, Ru_3apoMb, and Ru_3Mb suggest that the presence of a dioxygen binding site in Ru_3Mb greatly enhances the base line turnover rate of an a_3RuIm^{3+}-type catalytic system (Table I). In view of the proximity of His-113 to the heme (Figure 2), it is likely that $a_3Ru(His-113)^{2+}$ transfers an electron rapidly to the heme–dioxygen complex,[15] thereby producing some form of heme-bound peroxide intermediate (whose dissociation may prove to be the rate-limiting step). Clearly, our preliminary work has established that Ru_3Mb is an interesting multisite catalytic system that deserves detailed mechanistic examination.

(11) The reaction between {Ru(NH3)5H2O](PF6)2 (40-fold excess) and sperm whale myoglobin (Type II, Sigma) at room temperature (pH 7.3; 0.05 M Tris-HCl) was terminated by applying the solution to a Sephadex G-25 column. The Ru3Mb sample was oxidized by Co(phen)3(ClO4)3 and then separated from unreacted Mb by using a CM-52 column (linear gradient of NaCl in 50 mM Tris-HCl, pH 7.3). Ru3Mb was characterized by isoelectric focusing on LKB ampholine PAG plates (pH range 3.5–9.5; native Mb, pH ~7; Ru3Mb, pH ~9.2); the Ru:Mb ratio was determined to be 3:1 (±3%) by employing [106Ru(NH3)5Cl]Cl2 to prepare 106Ru(NH3)5H2O2+ and analyzing 106Ru in the protein derivative.
(12) The imidazole C-2 proton resonances in native sperm whale Mb have been assigned (Botelho, L. H.; Friend, S. H.; Matthew, J. B.; Lehman, L. D.; Hanania, G. L. H.; Gurd, F. R. N. *Biochemistry* 1978, *17*, 5197–5205).
(13) Isolation of the His-81- and His-113-containing tryptic peptides of Ru3Mb has confirmed those two a3Ru3+ attachment sites, but the His-12-containing peptide has eluded characterization, owing in part to its poor solubility properties (Shelton, J. B.; Shelton, J. R.; Schroeder, W. E., unpublished results). However, the presence of an a3Ru(His-12)3+ unit may be inferred from our observation that the fluorescence of nearby tryptophans (Trp-7, Trp-14) in apoMb is strongly quenched in Ru3apoMb.
(14) Very concentrated cyanide solutions ([CN⁻] ~ 1 M; [Mb] ~ 40 μM) are required for >95% formation of the Mb(Fe2+)-(CN⁻) complex (Keilin, D.; Hartree, E. F. *Biochem. J.* 1955, *61*, 153–171). In contrast, >95% formation of Ru3Mb(Fe2+)-(CN⁻) occurs at [CN⁻] ~ 0.1 mM for [Ru3Mb-(Fe2+)] ~ 10 μM.
(15) Dioxygen reduction by ruthenium(II) ammine complexes apparently involves formation of superoxide anion as a reactive intermediate (Stanbury, D. M.; Haas, O.; Taube, H. *Inorg. Chem.* 1980, *19*, 518–524). It would be highly surprising if reduced Ru3Mb with its multiple redox centers did not choose a more felicitous route to peroxide. Indeed, our observation that reduced Ru3Mb reacts much more rapidly than a3RuL2+ with dioxygen indicates that it does.

Structure and Reactivity of Sterically Hindered Lithium Amides and Their Diethyl Etherates: Crystal and Molecular Structures of [Li{N(SiMe3)2}(OEt2)]2 and [Li(NCMe2CH2CH2CH2CMe2)]4

Michael F. Lappert,* Martin J. Slade, and Anirudh Singh

School of Chemistry and Molecular Sciences
University of Sussex, Brighton BN1 9QJ, England

Jerry L. Atwood,* Robin D. Rogers, and Riz Shakir

Department of Chemistry, The University of Alabama
University, Alabama 35486

Received July 12, 1982

Bulky amides of the alkali metals are extensively employed as reagents in organic chemistry by virtue of the combination of their strong Brønsted basicity and their low nucleophilicity, especially with respect to electrophilic carbon centers;[1] lithium derivatives of secondary amines have a particularly pivotal role. An objective of the present communication is to provide X-ray structural data for two of the key compounds, bis(trimethylsilyl)amido-[2] and (2,2,6,6-tetramethylpiperidinato)lithium in order to place the steric arguments on a firm basis. A further purpose is to note that these compounds are not only bases but also Lewis acids,[3] and hence the choice of donor solvent may be significant.[4] The formation of a lithium amide solvate is expected to affect both the state of molecular aggregation of the amide[6,8] and its hydrocarbon solubility.[10] These properties are of considerable significance in making an appropriate choice of lithium amide reagent as an amido transfer reagent for the synthesis of an amide of another metal. In our own work, we have a strong preference for a *crystalline* lithium amide monoetherate as reagent, because of the following features: (i) confidence with regard to reagent purity and concentration, (ii) availability of a nonpolar solvent as the reaction medium, and (iii) ease of manipulation.[12]

(1) Cf.: Lappert, M. F.; Power, P. P.; Sanger, A. R.; Srivastava, R. C. "Metal and Metalloid Amides"; Ellis Horwood-John Wiley: Chichester, 1980; pp 689–691.
(2) The X-ray structure of [Li{N(SiMe3)2}]3 has been determined: Mootz, D.; Zinnius, A.; Böttcher, B. *Angew. Chem., Int. Ed. Engl.* 1969, *8*, 378. Rogers, R. D.; Atwood, J. L.; Grüning, R. *J. Organomet. Chem.* 1978, *157*, 229.
(3) The formation of a 1:1 OEt2 adduct of Li[N(SiMe3)2] has been noted: Wannagat, U.; Niederprüm, H. *Chem. Ber.* 1961, *94*, 1540.
(4) We believe that for metal amides this has not previously been explicitly stated; although for lithium alkyls the role of different solvents such as OEt2, THF, TMEDA, or PMDETA (pentamethyldiethylenetriamine), upon their structure and reactivity is beginning to be documented.[5]
(5) Lappert, M. F.; Raston, C. L.; Skelton, B. W.; White, A. H. *J. Chem. Soc., Chem. Commun.* 1982, 14.
(6) Variable-temperature ¹H and ⁷Li NMR spectra of Li[N(SiMe3)2] in several donor solvents were examined and the results interpreted in terms of a monomer ⇌ dimer equilibrium in solution.[7]
(7) Kimura, B. Y.; Brown, T. L. *J. Organomet. Chem.* 1971, *26*, 57.
(8) We suggest that the lower the state of molecular aggregation, the greater the amide reactivity and selectivity; the extreme case would be for a monomeric solvated lithium amide, and we predict that for example Li[N-(SiMe3)2](PMDETA) will prove to be a monomer in the crystal and will be outstandingly reactive and selective as a proton abstractor. As circumstantial evidence we cite the monomeric Li[CH(SiMe3)-o-MeC6H4](PMDETA).[9]
(9) X-ray data: Lappert, M. F.; Raston, C. L.; Skelton, B. W.; White, A. H., unpublished work.
(10) We find that although [Li{N(SiMe3)2}]3 and [Li{NCMe2-(CH2)3CMe2}]4 have some n-pentane solubility, this is significantly increased for [Li{N(SiMe3)2}(OEt2)]2 or [Li{NCMe2(CH2)3CMe2}(OEt2)]n (the structure of this compound, and hence the value of n, is not yet known). We had previously reported[11] that [Li(OAr)(OEt2)]2 (Ar = C6H2-4-Me-2,6-t-Bu2) is soluble in n-C6H14, whereas [Li(OAr)]n (of unknown structure) is insoluble.
(11) Cetinkaya, B.; Gümrükcü, I.; Lappert, M. F.; Atwood, J. L.; Shakir, R. *J. Am. Chem. Soc.* 1980, *102*, 2086.
(12) Our most recent papers on metal amides using [Li{N(SiMe3)2}]-(OEt2)]2 concerns [ErCl[N(SiMe3)2](μ-Cl)2Li(THF)2],[13] and using [Li{N-t-Bu2)(OEt2)], or [Li{NCMe2(CH2)3CMe2}(OEt2)]n concerns M(N-t-Bu2)2 or M[NCMe2(CH2)3CMe2]2 (M = Ge or Sn).[14]
(13) Lappert, M. F.; Singh, A.; Atwood, J. L.; Hunter, W. E. *J. Chem. Soc., Chem. Commun.* 1981, 1191.

Communications to the Editor

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Table I. Structural Comparisons of Three Crystalline Lithium Amides[a]

empirical formula	degree of molecular aggregation in crystal	coordination no. of Li	Li-N$_{av}$, A	Li-N-Li, deg	N-Li-N$_{av}$, deg	Si-N-Si, deg	Si-N$_{av}$, A
Li[NCMe$_2$(CH$_2$)$_3$CMe$_2$]	tetramer,[b] 2	2	2.00 (2)	101.5 (3)	168.5 (4)		
Li[N(SiMe$_3$)$_2$]	trimer,[c] 3	2	2.00 (2)	92 (2)	147 (3)	118.6 (9)	1.729 (4)
Li[N(SiMe$_3$)$_2$](OEt$_2$)	dimer,[d] 1	3	2.06 (1)	74.8 (8)	105.2 (8)	121.9 (4)	1.705 (3)

[a] The (LiN)$_n$ ring conformation in all cases is planar. [b] The four Li atoms and the four N atoms are each coplanar; the N atoms are less than 0.01 A out of the Li$_4$ plane. [c] Reference 2; the Li$_3$N$_3$ ring is planar to within 0.01 A. [d] Li-O, 1.95 (2) A; O-Li-N, 127.4 (4)°; Li-O-C, 121.7 (4)°; C-O-C, 116.6 (8)°, trigonal planar at both O and Li.
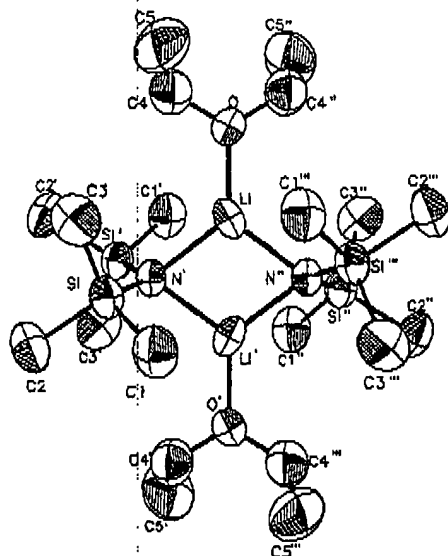

Figure 1. Molecular structure of {Li[N(SiMe$_3$)$_2$](OEt$_2$)}$_2$, 1, with the atoms represented by their 50% probability ellipsoids for thermal motion. The dimer resides about a crystallographic 222 site; one 2-fold axis contains the lithium and oxygen atoms, one the nitrogen atoms, and the third is perpendicular to the Li$_2$N$_2$ plane.

The crystal and molecular structure of Li[N(SiMe$_3$)$_2$](OEt$_2$) (1), illustrated in Figure 1,[15] shows the compound to be the bis(μ-bis(trimethylsilyl)amido)dilithium compound with terminal diethyl etherate molecules completing the three-coordinate lithium atom environment. As in [Li(OC$_6$H$_2$-4-Me-2,6-t-Bu$_2$(OEt$_2$)]$_2$,[11] both the lithium and ether oxygen atoms are trigonal planar, and the Li-OEt$_2$ bond lengths are comparable, 1.961 (11) Å in the aryl oxide. Figure 1 also demonstrates the lipophilic character of compound 1, a feature also evident for the aryl oxide.

The crystal and molecular structure of [Li[NCMe$_2$(CH$_2$)$_3$CMe$_2$]$_4$ (2), illustrated in Figure 2,[16] shows the compound to have a planar eight-membered (LiN)$_4$ ring, with each piperidine ring
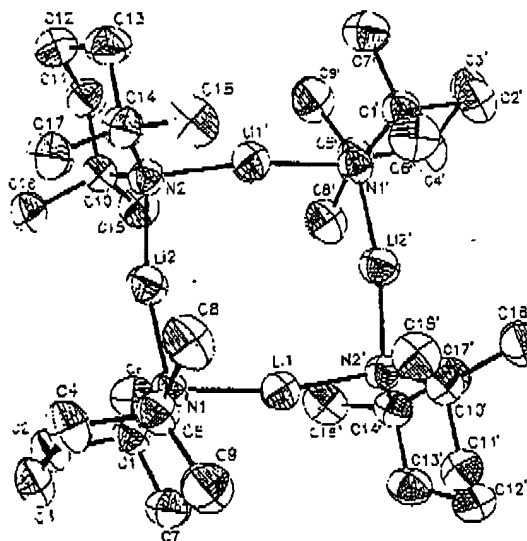
(14) Lappert, M. F.; Slade, M. J.; Atwood, J. L.; Zaworotko, M. J. *J. Chem. Soc., Chem. Commun.* 1980, 621.

(15) Compound 1 crystallizes in the tetragonal space group *P*4n2, with lattice constants a = 9.790 (3) A, c = 17.284 (5) Å, and D_c = 0.92 g cm^{-3} for two dimers in the unit cell. Data were collected on the CAD-4 diffractometer in the usual manner: Holton, J.; Lappert, M. F.; Ballard, D. G. H.; Pearce, R.; Atwood, J. L.; Hunter, W. E. *J. Chem. Soc., Dalton Trans.* 1979, 45. Least-squares refinement based on 604 observed reflections led to a final R value of 0.051 (73 varied parameters). Hydrogen atoms were included with fixed contributions, and all non-hydrogen atoms were refined with anisotropic thermal parameters. A series of ψ scans showed that an absorption correction was unnecessary.

(16) Compound 2 crystallizes in the monoclinic space group *C*2/*c*, with lattice constants a = 16.673 (6) A, b = 16.584 (6) A, c = 15.893 (6) Å, β = 116.76 (4)°, and D_c = 1.00 g cm^{-3} for two tetramers in the unit cell. Data were collected as for 1. Least-squares refinement based on 1369 observed reflections led to a final R value of 0.044 (198 varied parameters). Hydrogen atoms were included with fixed contributions, and all non-hydrogen atoms were refined with anisotropic thermal parameters. As with 1, no absorption correction was necessary.

Figure 2. Structure of [Li(NCMe$_2$CH$_2$CH$_2$CH$_2$CMe$_2$]$_4$, 2.

Table II. Some Data for Bulky Lithium Amides[a]

compound	yield,[b] %	mp, °C
{Li[N(SiMe$_3$)$_2$](OEt$_2$)}$_2$, 1[c]	72	105-107[d]
{Li[NCMe$_2$(CH$_2$)$_3$CMe$_2$]}$_4$, 2	68	185-186 dec

[a] Analytically uncharacterized crystalline [Li(N-t-Bu$_2$)]$_n$ (76%) and [Li(N-t-Pr-t-Bu)]$_m$ (74%) were obtained from the appropriate amine and an equimolar portion of Li-n-Bu in n-C$_6$H$_{14}$. [b] This refers to isolated crystalline material. [c] ^{1}H NMR (assignments; C$_6$D$_6$) δ 9.63 [Si(CH$_3$)$_3$], 8.93 (CH$_2$CH$_3$), 6.45 (CH$_2$CH$_3$); ^{13}C NMR (ppm relative to C$_6$D$_6$ at 128.0 ppm, in C$_6$D$_6$) 6.05 [Si(CH$_3$)$_3$], 14.0 (CH$_2$CH$_3$), 63.51 (CH$_2$CH$_3$). [d] Cf.[5] mp 95-110 °C dec.

in chair conformation arranged in staggered relationship to one another so as to provide an inversion center. A two-coordinate lithium environment is not unique, having already been established for [Li[N(SiMe$_3$)$_2$]]$_3$ (3), which, however, has a planar hexagonal (LiN)$_3$ ring.[2] This difference reflects the greater steric demand of the 2,2,6,6-dimethylpiperidinato ligand compared with N-(SiMe$_3$)$_2$. A similar effect has been noted, inter alia in cyclic (XBNY)$_n$ chemistry, wherein the six-membered planar borazine (n = 3) provides the norm, but sterically demanding ligands X and Y may result in either a square-planar arrangement (n = 2) or a crown-shaped tetramer (n = 4).[17]

Some significant structural parameters on compounds 1-3 are summarized in Table I. Not unexpectedly the Li-N bond length is longer when the N(SiMe$_3$)$_2$ ligand occupies a bridging (1) rather than a terminal (3) role.

In one preparative experiment, 60 mL of 1.67 M (100 mmol) of n-butyllithium solution in n-hexane was added dropwise during

(17) Cf. ref 1, p 70.

ca. 2 h to a cooled (0 °C) and stirred solution of hexamethyl-disilazane (20 mL, 95 mmol) in 100 mL of diethyl ether. After stirring at 20 °C for ca. 2 h, the white crystals were filtered off, washed with cooled n-hexane, dried in vacuo, and recrystallized from cold OEt₂–n-C₅H₁₄ to afford the analytically pure, air-sensitive compound (1).

In another preparation, n-butyllithium (37 mL of a 1.6 M solution in n-C₆H₁₄, 59.2 mmol) was added dropwise during ca. 1/2 h to a stirred solution of 2,2,6,6-tetramethylpiperidine (10 mL, 59.4 mmol) in n-C₅H₁₂ (40 mL). The reaction mixture slowly became opalescent, and after stirring overnight, a white precipitate and pale yellow solution was observed. The mixture was filtered, and the white solid was washed with cold (0 °C) n-pentane and pumped dry to give the very air-sensitive, slightly pyrophoric, crystals of analytically pure compound (2).

Supplementary Material Available: Tables of bond distances and angles, final fractional coordinates, thermal parameters, and observed and calculated structure factor amplitudes for 1 and 2 (19 pages). Ordering information is given on any current masthead page.

Silane Surface Chemistry of Palladium: Synthesis of Silaethylene, Silacyclobutadiene, and Silabenzene

Thomas M. Gentle and E. L. Muetterties*

*Materials and Molecular Research Division
Lawrence Berkeley Laboratory
and Department of Chemistry, University of California
Berkeley, California 94720*

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Chemisorption of cycloalkenes on metal surfaces are followed by dehydrogenation processes[1] that often give chemisorbed C$_n$H$_n$ species, e.g., cyclohexene → benzene[1-3] and cyclooctadiene → cyclooctatetraene.[3] Because these transformations are facile, we have been exploring the reactions of organosilanes with single-crystal metal surfaces[4] as routes to compounds in which there are Si–C bonds of multiple bond order. With platinum and nickel, we observed either no dehydrogenation or gross degradation of the silaalkane.[5] Palladium, however, has furnished dehydrogenation syntheses of silaethylenes, silabenzene, and what appears to be silacyclobutadiene.[6]

Tetramethylsilane on Pd(110) desorbed fully and intact at ~–50 °C analogous to neopentane on Pd(110), which quantitatively desorbed with a T_{max} of ~–60 °C. In sharp contrast, trimethylsilane after adsorption at –135 °C underwent two competing thermal processes: (i) reversible desorption with a maximum desorption rate at –20 °C; (ii) dehydrogenation to form

(CH₃)₂Si=CH₂,[8,9] which desorbed with maximum rates at –40 and +90 °C (the surface was essentially free of Si and C after the desorption experiment). The latter process was accompanied by H₂ desorption, which also exhibited maxima at –40 and +90 °C. Minor dimerization of the silaethylene also occurred: [–Si(CH₃)₂CH₂–]₂ desorbed to give a broad peak at ~40 °C. An unexpected feature here was desorption of silaethylene because most alkenes and alkynes *irreversibly* chemisorb on clean transition-metal surfaces. Consistent with the organosilane surface chemistry, we have found that acetylene and ethylene chemisorb on Pd(110) in a partially reversible fashion.[10]

Displacement of the silaethylene, (CH₃)₂Si=CH₂, from the Pd(110) surface was effected with P(CH₃)₃. On dosing the crystal face with P(CH₃)₃ at +25 °C, there was immediate displacement of the silaethylene, the dimer, [–Si(CH₃)₂CH₂–]₂, and trimethylsilane.

The silaethylene (CH₃)₂Si=CH₂ was also produced in the thermal desorption experiments with (CH₃)₃SiOSi(CH₃)₃, (CH₃)₃SiNHSi(CH₃)₃, and (CH₃)₃SiN₃ on Pd(110). All three also exhibited partially reversible chemisorption. In the azide system, an additional and major product was [–(CH₃)₂SiN(CH₃)–]₂.

Silacyclobutane displayed a complex Pd(110) surface chemistry. After adsorption at –135 °C, silanes 1–4 were observed in the
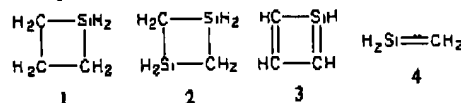
thermal desorption with respective desorption maxima at ~–65, +65, +50, and +70 °C, respectively. Ethylene and hydrogen were observed with similar T_{max} of 60–80 °C. All these species were observed in a chemical displacement reaction with P(CH₃)₃. Silacyclobutadiene is a new compound, and its characterization must be considered tentative in that it is based solely on mass spectrometric data. The parent ion was less intense than the parent-minus-one ion, as expected for a species with one Si–H bond. Ostensibly, silaethylene[9c] was the precursor to the dimer 2. Consistent with this presumption, the ratio of 4 to 2 increased when the heating rate was increased from 25 to 75 °C s⁻¹.

Silacyclohexane, initially adsorbed on Pd(110) at –135 °C, also underwent two competing surface reactions: reversible desorption ($T_{max} = –25$ °C) and dehydrogenation to give silabenzene,[12] SiC₅H₆ (two T_{max} of 90 and 190 °C), and H₂ (two T_{max} of 15 and 190 °C). This chemistry parallels that of cyclohexene, which gave benzene with a T_{max} (C₆H₆) of 220 °C and also of piperidine, which gave pyridine with T_{max} (NC₅H₅) of 115 and 155 °C.[10] Silabenzene was not displaced by P(CH₃)₃ from the surface generated from silacyclohexane at temperatures of 25–70 °C.

There are a number of remarkable features to this Pd(110) chemistry. One is the extensive degree of reversible chemisorption of unsaturated hydrocarbons like acetylene, ethylene, and of course, silaethylene and silabenzene. Secondly, these results suggest a practical synthesis of silaethylenes, silacyclobutadienes, and silabenzenes by palladium-catalyzed dehydrogenation of organosilanes, an aspect now under study in our laboratories.[13,14] Also,

(1) Tsai, M.-C.; Stein, J.; Friend, C. M.; Muetterties, E. L. *J. Am. Chem. Soc.* 1982, 104, 3533–3534.

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(3) (a) Tsai, M.-C.; Friend, C. M.; Muetterties, E. L. *J. Am. Chem. Soc.* 1982, 104, 2539–2543. (b) Tsai, M.-C.; Muetterties, E. L. *J. Phys. Chem.* 1982, 86, 5067.

(4) See references in ref 3 for the equipment, techniques, and procedures for these ultrahigh vacuum experiments. Adsorption was generally effected at –135 °C, and desorption studies were usually done with 25 °C s⁻¹ heating rates.

(5) Tsai, M.-C.; Friend, C. M.; Johnson, A. L.; Muetterties, E. L., unpublished data.

(6) The contrasting behavior of palladium with respect to platinum might be traced to a uniquely low Pd–Si bond energy.[7]

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(8) This compound was characterized only by its mass spectrum. The essential absence of a parent-minus-one ion clearly indicated that this species contained no Si–H bond. This silaethylene molecule has been prepared by thermolysis of tetramethylsilane and trimethylsilane.[9] The alternative formulation of such species as silylenes is critically reviewed by Schaefer.[9c]

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(11) References to the generation by thermal processes, mass spectrum, and trapping of silabenzene are given in ref 12.

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(13) Since compounds with Si–C multiple bonds readily dimerize or polymerize, the ultrahigh vacuum reaction conditions are ideal for observation of such compounds. However, this technique is impractical for the generation of sufficient quantities for chemical trapping experiments. We plan to examine Pd-catalyzed organosilane dehydrogenation reactions under flow conditions by using very short contact times and matrix or chemical trapping conditions.

Exhibit 3

Table I. Photochemical and Photophysical Data for Cyanine Borates

solvent	cyanine lifetime,^{a} ps; $[\phi_{fl}]^b$				$k_{et},^d 10^{10}$ s^{-1}	
	PF$_6^-$	(C$_6$F$_5$)$_4$B$^-$	(TRPPh)$_4$B$^-$	(C$_6$H$_{11}$Ph)$_4$B$^-$	(C$_6$H$_{11}$Ph)$_4$B$^-$	(TRPPh)$_4$B$^-$
toluene	300; [0.048]	350; [0.05]	490; [0.04]	13;^{c} [0.002]	7.1	<0.20
benzene	250; [0.047]	340; [0.05]	520; [0.05]	28;^{c} [0.005]	2.6	<0.20
p-xylene	350; [0.066]	410; [0.06]	400; [0.03]	8;^{c} [0.001]	13	<0.25
tetralin	435; [0.066]	580; [0.11]	670; [0.04]	6;^{c} [0.001]	20	<0.15
p-cymene	e; [e]	520; [0.11]	520; [0.02]	13;^{c} [0.003]	7.5	<0.20

^{a} Determined by monitoring the rate of ground state absorption recovery or excited state absorption decay following laser excitation. Standard deviations from independent measurements are ±20 ps. ^{b} Quantum yield of fluorescence determined by excitation at 532 nm for PF$_6^-$ salts and 526 nm for the others. ^{c} The lifetime of the excited cyanine is too short to measure with an 18-ps laser pulse. These values were computed from the fluorescence yields and the assumption that the radiative and nonradiative rates are the same as for the (C$_6$H$_5$)$_4$B$^-$ salt. ^{d} Rate constant for electron transfer calculated from the ratio of fluorescence efficiencies of Cy$^+$[(C$_6$F$_5$)$_4$B$^-$] and Cy$^+$[(C$_6$H$_{11}$Ph)$_4$B$^-$] and the lifetime of Cy$^+$[(C$_6$F$_5$)$_4$B$^-$] as described in ref 8. ^{e} The solubility is too low for accurate measurement of the lifetime and fluorescence yield.

The decrease in fluorescence efficiency and lifetime for Cy$^+$[(C$_6$H$_{11}$Ph)$_4$B$^-$] (borate E_{OX} = 1.14 V vs SCE) compared with those for the perfluorophenyl borate is attributed to electron transfer from the borate to the excited cyanine in accord with observations in related systems.[10,11] Obviously, electron transfer in [(Cy$^+$)^{*1}(TRPPh)$_4$B$^-$] is inhibited by the change in the substituent on the phenyl groups of the borate from a cyclohexyl to a triptycenyl group. Since this change will have little effect on E_{OX} of the borate, the inhibition of electron transfer must have a steric origin.

The formation of the mono-cis isomer from irradiation of cyanine dyes is generally solvent dependent.[13] We investigated the isomerization of the cyanine borates described in Chart I to probe the microscopic environment of the medium surrounding the cyanine dye. The absorption due to the mono-cis isomer 100 ns after irradiation of the cyanine ion pair in benzene solution (532 nm, 25 ns, 20 mJ) is readily apparent when the anion is [(C$_6$F$_5$)$_4$B$^-$] or PF$_6^-$, but is completely absent for the [(C$_6$H$_{11}$Ph)$_4$B$^-$] and [(TRPPh)$_4$B$^-$] salts. Inhibition of isomer formation for the [(C$_6$H$_{11}$Ph)$_4$B]$^-$ salt is easily explained since rapid electron transfer competes with bond rotation in the excited singlet state of this compound. Surprisingly, both electron transfer and bond rotation are inhibited in [(Cy$^+$)^{*1}(TRPPh)$_4$B$^-$].

The structures of these salts shown in Figure 1 were computed using PCMODEL.[15] The calculations indicate that energy minimization requires striking a balance between the strong electrostatic attraction of the oppositely charged ions and steric repulsion. For [Cy$^+$(TRPPh)$_4$B$^-$], movement of the phenyltriptycenyl groups away from the symmetrical structure of the free ion opens a cavity that accommodates penetration by the cyanine cation. In this ion pair the central methylene chain and the heteroaryl groups of the cyanine are encased in the borate. For the smaller Cy$^+$[(C$_6$F$_5$)$_4$B$^-$], the cyanine cation does not penetrate the interior of the borate anion significantly. The chemical and physical properties of this salt are consistent with the contact ion pair structure depicted in Figure 1. Further experiments are required to test the validity of these predictions, which provide, at least, a guide to selection of additional structures.

When the cyanine is within the anion, as in [Cy$^+$(TRPPh)$_4$B$^-$], it cannot rotate to form the mono-cis isomer without cooperative motions in the borate. For the smaller borates, cyanine bond rotation remains operational and the singlet lifetime shows a solvent dependence since formation of the mono-cis isomer requires movement of solvent molecules. The magnitude of k_{et} similarly is strongly dependent on the structural details of the penetrated ion pair since it is much smaller for [Cy$^+$(TRPPh)$_4$B$^-$] than it is for [Cy$^+$(C$_6$H$_{11}$Ph)$_4$B$^-$]. Clearly, penetrated cyanine borate

ion pairs have unique, experimentally observable properties that depend on the structural details.

Distinction of Symmetric Lithium Dialkylamide Dimers from Higher Oligomers by Inverse-Detected 15N Homonuclear Zero-Quantum NMR Spectroscopy

James H. Gilchrist* and David B. Collum*

*Department of Chemistry, Baker Laboratory
Cornell University, Ithaca, New York 14853-1301*

6Li and 15N NMR spectroscopy have played a prominent role in the characterization of solvation, aggregation, and mixed aggregation equilibria of lithium dialkylamides.[1-8] It has been suggested that a range of lithium amide cyclic oligomers can exist in hydrocarbon solutions, but that only cyclic dimers are observable in donor solvents.[9] Despite mounting indirect spectroscopic,[2-5] kinetic,[7,10] and theoretical[9,11,12] evidence in support of this model, however, the high symmetry of the more synthetically important lithium dialkylamides has precluded a direct distinction of cyclic dimers (1) from other cyclic oligomers (e.g., trimer 2). We report
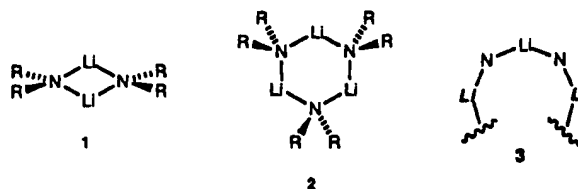
herein a simple NMR experiment in which indirectly detected homonuclear zero-quantum coherence[13] unambiguously differ-

Figure 1. Pulse sequence used to measure 6Li-detected 15N zero-quantum NMR spectra. Zero-quantum coherence was selected by cycling the third 15N pulse through four phases (0°, 90°, 180°, 270°) and adding the resulting free induction decays.

(15) The structures were calculated with the PCMODEL 4.0 program available from Serena Software, Bloomington, IN. The cyanine dye and the borate were independently minimized and then minimized as the ion pair in a variety of geometries. In this process the cationic dye was positioned within the borate at a distance closer than the van der Waals contact. Minimization results in an ion-pair structure of lower energy than the free ions. A range of possible starting structures was examined, and the minimized structures shown in Figure 1 represent the lowest energy obtained. However, these structures reflect only steric and Coulombic interactions; they ignore effects of solvation and possible kinetic prohibition to their formation.
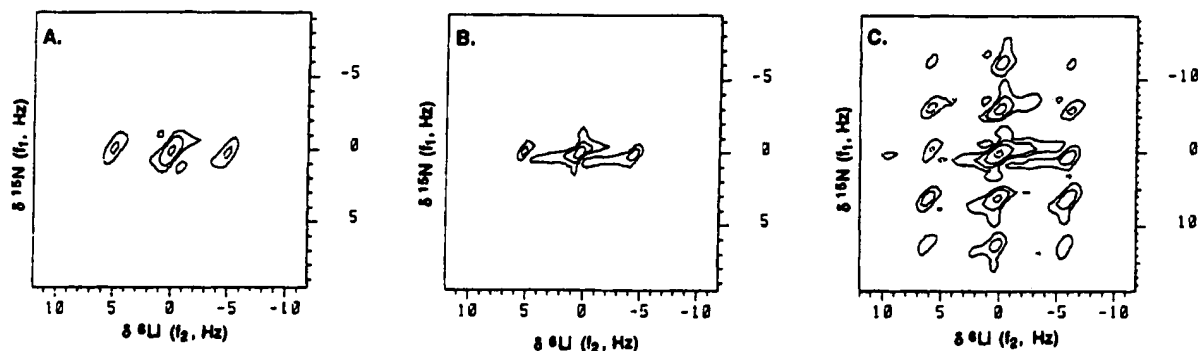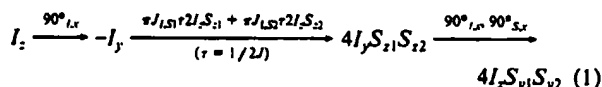
Figure 2. ^{6}Li-detected ^{15}N zero-quantum NMR spectra of (A) 0.15 M [^{6}Li,^{15}N]LDA in THF at −90 °C, (B) 0.10 M [^{6}Li,^{15}N]LiTMP in 3:1 THF/pentane at −115 °C, and (C) 0.25 M [^{6}Li,^{15}N]LiTMP in 3:1 benzene at 30 °C. Spectra were recorded on a Bruker AC 300 spectrometer operating at 44.17 MHz and 30.42 MHz for ^{6}Li and ^{15}N (respectively) with hardware modifications described previously.[2] Data were processed in the phase-sensitive mode. Digital resolution in f_1 prior to zero filling is 2.0 Hz, 1.0 Hz, and 2.4 Hz (respectively) for spectra A–C.

entiates cyclic dimers from higher oligomers of lithium diiso-propylamide (LDA)[5,7] and lithium 2,2,6,6-tetramethylpiperidide (LiTMP).[6]

$$I_z \xrightarrow{90°_{1x}} -I_y \xrightarrow{\tau J_{1,S1}r2I_zS_{z1} + \tau J_{1,S2}r2I_zS_{z2}}{(\tau = 1/2J)} \; 4I_yS_{z1}S_{z2} \xrightarrow{90°_{1x}\,90°_{Sx}}$$

$$4I_xS_{y1}S_{y2} \quad (1)$$

We employed the pulse sequence developed by Müller[14] and Bodenhausen and Ruben[15] for heteronuclear shift correlations (Figure 1). For the phases shown, homonuclear ^{15}N two-spin coherence (a mixture of zero- and double-quantum coherence) is prepared from the two ^{15}N spins neighboring a ^{6}Li atom in a ^{6}Li–^{15}N doubly labeled lithium dialkylamide cyclic oligomer (eq 1).[16] The precession of the zero-quantum coherence during t_1 is modulated by an effective scalar coupling to adjacent ^{6}Li nuclei.

(1) For additional leading references to ^{6}Li–^{15}N double labeling studies of lithium amides and related N-lithiated species, see ref 3.

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The effective coupling constant (J_{eff}) is defined[17] as

$$J_{eff} = \Delta m_{N1}J_{N1-Li} + \Delta m_{N2}J_{N2-Li} = (\pm1)J_{N1-Li} + (\mp)J_{N2-Li}$$

where Δm_{N_n} is the change in quantum number for the ^{15}N nucleus, n, involved in the coherence, and J_{N_n-Li} is the scalar coupling constant[18] between the ^{6}Li nucleus and ^{15}N$_n$. A ^{6}Li spin coupled equally to ^{15}N$_1$ and ^{15}N$_2$ does not cause splitting of the zero-quantum line in the f_1 (^{15}N) dimension ($J_{eff} = 0$). For ^{6}Li spins coupled to one ^{15}N spin (but not both), $J_{eff} = \pm J_{N_n-Li}$. As a consequence, the multiplicity of the zero-quantum line reveals the number of ^{6}Li spins adjacent to (but not shared by) the ^{15}N–^{15}N two-spin system. For a lithium amide dimer, all ^{6}Li spins coupled to ^{15}N spins involved in the two-spin coherence are coupled to *both* ^{15}N spins. The coupling pattern will be a singlet along the f_1 dimension of the two-dimensional spectrum and a 1:–2:1 triplet along the f_2 dimension. In the case of higher cyclic oligomers, there exist two ^{6}Li spins (*Li* in 3) that are coupled to one ^{15}N spin, but not both. The zero-quantum coherence will develop scalar coupling to the two nonshared ^{6}Li spins, resulting in a 1:2:3:2:1 pattern along the f_1 dimension and a 1:–2:1 pattern along the f_2 dimension.

The results of the experiment as applied to [^{6}Li,^{15}N]LDA[5] and [^{6}Li,^{15}N]LiTMP[6] in tetrahydrofuran (THF) solutions are illustrated in Figure 2 (A and B, respectively). The coupling patterns show that the aggregated forms are cyclic dimers rather than higher oligomers in both cases. The complementary outcome is illustrated by the spectrum of [^{6}Li,^{15}N]LiTMP in benzene (Figure 2C). The ^{6}Li triplet corresponding to the major[19] cyclic oligomer shows a 1:2:3:2:1 splitting pattern along f_1 consistent with a higher oligomer rather than the dimer.

Registry No. LDA, 4111-54-0; LDA cyclic dimer, 137668-29-2; LiTMP, 38227-87-1; LiTMP cyclic dimer, 137003-53-3.

(18) Three-bond ^{15}N–^{6}Li scalar coupling has not been observed.

(19) A minor (approximately 10%) oligomer of LiTMP in benzene is readily observable by standard one-dimensional ^{6}Li and ^{15}N NMR spectroscopy, but is below the lowest contour of Figure 2C.

Exhibit 4

COUDERT ET AL.

EY, C. SELVE, J.J. DELPUECH,

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T. HAKUSHI,

ation of hexaethylene glycol

and particularly cleavage of

DEHYDROHALOGENATION REACTIONS USING HINDERED LITHIUM DIALKYLAMIDE BASES

Ihor E. Kopka[1], Michael A. Nowak and Michael W. Rathke*

Department of Chemistry, Michigan State University,
East Lansing, Michigan 48824

The E2 eliminations of 2-substituted butanes with a series of hindered lithium dialkylamide bases has been exmined. Excellent yields of butenes are obtained using 2-bromobutane and 2-iodobutane. Alkyl chlorides, acetates and tosylates give poor yields of olefin product. Elimination reactions show a rise, then a fall, in the 1-butene/2-butene(s) product ratio as the amide bulk increases. Dehydrohalogenation of 2-bromobutane with lithium 2,2,6,6-tetramethylpiperidide in the presence of one equivalent of 12-crown-4 gives 1-butene/2-butene(s) product ratio of 99:1.
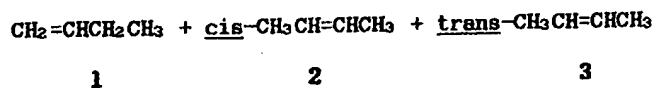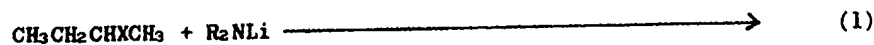
Base promoted β-eliminations have been an intensively studied area in organic chemistry. Recent reviews[2] have summarized the effects of 2-alkyl groups, solvent and base in these elimination reactions. These factors determine what position the β-elimination takes in the variable E2 transition-state spectrum. Careful control of those variables can lead to a high degree of selectivity of Hoffman or Saytzeff product.

It has been reported[3] that a high degree of association between an anionic base and its countercation lead to increased

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*To whom correspondence should be addressed.

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basicity and enhanced proportions of Hoffman elimination product in

bimolecular eliminations. This high degree of association has been

achieved via the preparation of hindered alkoxides[3] and "self-

solvating" bases.[4] The former has led us to investigate the

synthesis[5] and reactions[6] of a series of hindered secondary amines

and their corresponding lithium dialkylamides. Lithium 2,2,6,6-

tetramethylpiperidide, readily prepared from 2,2,6,6-tetramethyl-

piperidine (TMP), the most hindered commercially available

secondary amine, has been shown to be a highly proton-selective[7]

and non-nucleophilic[8] base.

The E2 reaction of alkyl halides with lithium dialkylamides

has not been well studied, and there are only a few references to

synthetic or physical organic investigations of dialkylamide-

initiated E2 reactions.[4,9] This study was initiated to investigate

the regiochemical and stereochemical influence of dialkylamide

$$CH_3CH_2CHXCH_3 + R_2NLi \xrightarrow{\hspace{5cm}} \hspace{2cm} (1)$$

$$CH_2=CHCH_2CH_3 + \underline{cis}-CH_3CH=CHCH_3 + \underline{trans}-CH_3CH=CHCH_3$$

$$1 \phantom{=CHCH_2CH_3 + \underline{cis}-CH_3}2 \phantom{CH=CHCH_3 + \underline{trans}-CH_3CH}3$$

base-promoted dehydrohalogenations (eq. 1). We wish to report that

lithium 2,2,6,6-tetramethylpiperidide (LiTMP), in the presence of

12-crown-4, gives exceptional selectivity in the dehydrohalogenation

of 2-bromobutane.

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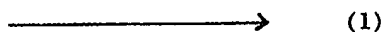
3

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The dehydrohalogenation of 2-bromobutane and 2-iodobutane with lithium dialkylamides in THF solution proceed in good yields. 2-Butyl acetates and tosylates gave less than 20% yields after 10 hours. Diethyl ether solvent is ineffective in promoting the reaction. The elimination reaction with a series of increasingly hindered lithium dialkylamides shows a rise and then a fall in the 1-butene/2-butene(s) product ratio (Table 1). This is what would be expected for E2 reactions with increasingly hindered bases. The Hoffman product preference can be rationalized using a simple steric model, assuming an anti-elimination transition state. This model is similar to the one proposed[2c] for E2 reactions using aggregated alkoxide bases of small to moderate steric dimensions.

The dehydrohalogenation of 2-bromobutane was examined in the presence of 12-crown-4, hoping to reduce the aggregate state of the amide bases and observe what effect this would have on product distribution. The results, summarized on Table 2, show no significant effect except for LiTMP which shows an increase in the 1-butene/2-butene(s) ratio as well as the cis/ trans 2-butene ratio.

Whether or not the amide bases are associated, a simple steric model appears adequate to explain the experimental results, at least for the low and moderately hindered amide bases. For the very bulky amide bases, the simple model fails. Decreasing rates of reaction as well as a decrease in selectivity suggest the most-hindered bases are too hindered to coordinate to the β-methyl or β-methylene H atom of the alkyl halide. Space filling models show the nitrogen atom is effectively shielded by the alkyl sidechains,

Table 1. Product Ratios for the Dehydrohalogenation of 2-Halobutanes[a] with Hindered Lithium Dialkylamides in THF at 0°C.

$$CH_3CH_2CHXCH_3 + R_2NLi \longrightarrow 1 + 2 + 3$$

Entry	R	T_{50}[d]	T_{90}[d]	1	2	3	2/3	Yield (1+2+3), %
1	Et	1 min	5 min	55(37)	31(21)	13(41)	2.4(1.9)	97(97)
2	i-Pr	30 min	1.5 h	67(40)	22(22)	11(38)	2.0(1.7)	80
3b	i-Pr			67	22	11	2.0	90
4	TMP	5 min	1 h	86(61)	7(19)	7(20)	1.0(1.05)	81(97)
5b	TMP			85	8	7	1.2	80
6	EtMe₂C	15 min	2 h	90(69)	6(12)	4(18)	1.5(1.5)	82(97)
7	Et₂MeC			71(38)	23(20)	6(42)	3.8(2.1	56(84)
8	Et₃C	11 h	90 h	55(28)	36(23)	9(49)	4.0(2.2)	74(85)
9c	i-Pr	20 h		69	20	10	2.0	64

a) Results in parenthesis are for 2-Iodobutane. All other entries are for 2-Bromobutane.

b) One equivalent of TMEDA present in all reactions except entries 3 and 5.

c) Results obtained with 2-chlorobutane.

d) T_{50} and T_{90} correspond to the time required to achieve a 50% yield and 90% yield, respectively.

7	Et₂MeC			71(38)	23(20)	6(42)	3.8(2.1)	56(84)
8	Et₃C	11 h	90 h	55(28)	36(23)	9(49)	4.0(2.2)	74(85)
9ᶜ	i-Pr	20 h		69	20	10	2.0	64

a) Results in parenthesis are for 2-Iodobutane. All other entries are for 2-Bromobutane.

b) One equivalent of TMEDA present in all reactions except entries 3 and 5.

c) Results obtained with 2-chlorobutane.

d) T₅₀ and T₉₀ correspond to the time required to achieve a 50% yield and 90% yield, respectively.

Table 2. Dehydrohalogenation of 2-Bromobutane with Hindered Lithium Dialkylamides in the Presence of 12-Crown-4.

$$CH_3CH_2CHBrCH_3 + R_2NLi \xrightarrow[\text{12-C-4}]{\text{THF,0°C}} \underset{\mathbf{1}}{CH_2=CHCH_2CH_3} + \underset{\mathbf{2}}{cis\text{-}CH_3CH=CHCH_3} + \underset{\mathbf{3}}{trans\text{-}CH_3CH=CHCH_3}$$

Entry	R	Equiv. of 12-crown-4	1	2	3	2/3	Yield (1+2+3),%
1	Et	1.0	53	29	18	1.6	
2	i-Pr	1.0	71	19	10	1.9	74
3	TMP	1.0	99	0.5	0.5		100
4ᵃ	TMP	1.0	99	0.5	0.5		99
5	TMP	0.5	95	2.5	3.5	0.7	
6	TMP	0.25	92	3.0	4.5	0.67	
7	TMP	0.1	89	4.0	7.0	0.56	
8	EtMe₂C	1.0	88	5.0	7.0	0.7	75
9	Et₂MeC	1.0	53	32	15	2.1	33
10	Et₃C	1.0	40	45	15	3.0	36

a) All reactions run in the presence of one equivalent of TMEDA, except entry 4.

burying the anionic center within the hydrocarbon folds of the

molecule. The result of this shielding is to make the very

hindered amide bases less kinetically basic. The effect of crown

ethers on the product ratios obtained using lithium tetramethyl-

piperidide is opposite that observed using potassium t-butoxide.

It has been proposed that crown ethers reduce the state of aggre-

gation of alkoxide bases in alcohol, thus reducing the steric

requirements of the associated base species and is reflected by a

decrease in the proportion of Hoffman product. An increase in the

Hoffman product ratio when crown ethers are added to the moderately

hindered LiTMP may reflect a higher kinetic basicity of the

dissociated base. We are currently studying the mechanistic

aspects of this reaction.

EXPERIMENTAL

General Procedure for the Dehydrohalogenation of 2-Halobutanes.

A 10ml round-bottom flask fitted with a septum inlet, magnetic

stirrer, and gas inlet tube was connected to a mercury bubbler and

flame-dried under argon. The flask is charged with 1.88ml 1.6M

solution of n-butyllithium in hexane (3 mmol). If a lithium

dialkylamide of bulk equal to or greater than 4 is to be used,

0.45ml TMEDA (3 mmol) is added. The addition of TMEDA is otherwise

optional. The flask is cooled to 0°C with an ice bath. The

appropriate secondary amine (3 mmol) is added dropwise via syringe.

The ice bath is removed and the reaction mixture stirred 10

minutes. Metallation of bis(1,1-diethyl-2-propyl-)amine requires a

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basic. The effect of crown

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is added dropwise via syringe.

ion mixture stirred 10

ayl-2-propyl-)amine requires a

reaction time of 20 hours. The flask is placed in a warm water bath (40-50°C) and the hexane solvent removed under high vacuum. The flask was then cooled to 0°C and 3ml of THF added to the flask. If 12-crown-4 is to be added to the reaction mixture, the dissolved lithium amide is cooled to -78°C; otherwise, the reaction mixture is maintained at 0°C. Addition of 12-crown-4 is accomplished by adding 1.5ml of a 2.0M solution of crown ether in THF via syringe within 30 seconds. Care should be taken not to add crown ether to the reaction mixture at 0°C as this accelerates the metallation of THF. Pure 12-crown-4 will not dissolve in THF at -78°C even after 2 hours. The reaction mixture is stirred for one additional minute and 2-halobutane (3 mmol) and pentane (3 mmol) are added rapidly via syringe. Reaction mixtures containing crown ether are stirred at -78°C for 30 minutes, then warmed to 0°C for 2 hours. Reaction mixtures without crown ether are stirred at 0°C for 1 hour. Aliquots (10µ) were removed from the reaction flask and analyzed by gas chromatography using a Varian 920 gas chromatograph equipped with a 40' x 1/8" aluminum column packed with 80/100 mesh Chromasorb W with 20% SE-30. Pentane was used as internal standard. Quenching the reaction mixtures with water resulted in viscous gels which were difficult to sample. Results obtained from quenched and unquenched reaction mixtures were identical.

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